The Variable-Atmosphere Wave Tank

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Abstract

A facility was constructed for the study of water-entry, water-exit, and underwater trajectory behavior of small momentum-propelled missiles for varied trajectory launching angles, missile accelerations and velocities, wave fields and conditions of cavitation. A unique feature is the electromagnetic missile propulsion system. The facility is made principally of non-magnetic and electrically non-conducting materials to permit the determination of missile accelerating force from the reactive force on the launching coil.

Introduction

The Variable-Atmosphere Wave Tank at the California Institute of Technology, Pasadena, California, is a new facility designed for the study of water-entry, water-exit, and underwater trajectory behavior of small momentum-propelled missiles for varied trajectory launching angles, missile accelerations and velocities, wave fields, and conditions of cavitation.

Description of Facility

The diagram in Fig. 1 and the photograph in Fig. 2 show a reduced-pressure vessel constructed almost entirely of 2-inch-thick lucite sheet. The three flanged sections, bolted together with nylon bolts and sealed with O-rings are a wave generation section, a test section, and a wave-absorption section. The tank rests on four supports provided with screws for height adjustment and leveling. The two inner tank supports are heavy laminated wood piers with fiber-impregnated plastic bases and adjusting screws. The two outer tank supports are made of steel and the tank end-plate associated with the wave-generation equipment is of stainless steel. The floor of the tank is about 3 feet from ground level.

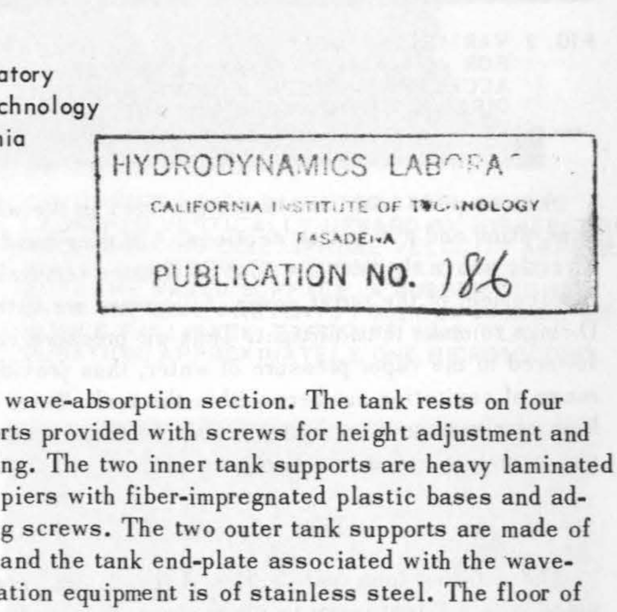

FIG. 1 DIAGRAM OF VARIABLE-ATMOSPHERE WAVE TANK.

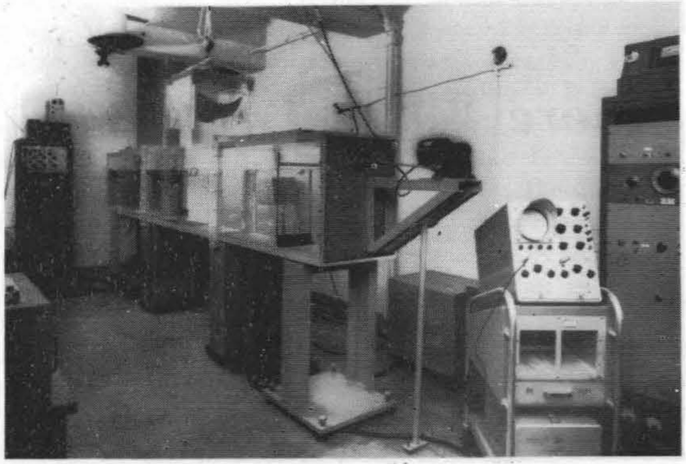

FIG. 2 VARIABLE-ATMOSPHERE WAVE TANK ADAPTED FOR VERTICAL WATER-EXIT STUDIES. A MISSILE-ACCELERATING COIL IS INSIDE THE TANK DIRECTLY BENEATH THE TURRET.

Access ports with covers are provided in the wave-generation and absorption sections. A trolley hand hoist, directly above the test section, facilitates removal and replacement of the turret cover. All covers are fitted with O-rings to make them airtight. Tank air pressure can be lowered to the vapor pressure of water, thus providing a range of cavitation numbers within the tank. Water of the high clarity necessary for metric stroboscopic photography is maintained with a Millipore filter.

Test Section

The 5.6-foot-long test section (Figs. 1 and 2) is provided with a 2-foot turret to allow some aerial trajectory. The turret has a removable airtight cover for missile loading and recovery. A nylon fabric backstop, impervious to moisture and molds, is mounted in the turret to halt missiles after water exit. The backstop, attached with nylon cords to eye-bolts at the corners of the turret, can be moved to one side for tank access.

Three 1-foot-diameter holes in the floor of the test section provide for mounting missile launching systems. One hole is directly beneath the turret for vertical or near-vertical upward launchings; the other two are on either side for oblique launchings into the turret. The missile may be launched either into the advancing wave or away from it. When not in use, the holes are fitted from underneath with plates so constructed as to make the channel bed uniformly level.

The tank and supports near the test section are constructed of plastics and wood that are non-magnetic and electrically nonconducting to permit determination of missile virtual or added mass by means of an electromagnetic missile propulsion system that is described later. The action of this system is illustrated in Fig. 1, which shows a steel sphere launched vertically upwards from a well, mounted beneath the central hole of the tank floor by means of a missile accelerating or launching coil. Different types of wells that could be used are shown in Fig. 3. In other applications, the launching coil (in suitable housing) could be submerged (as in Fig. 2) and missiles launched under water in any direction. The system could also be used for water-entry launching tests.

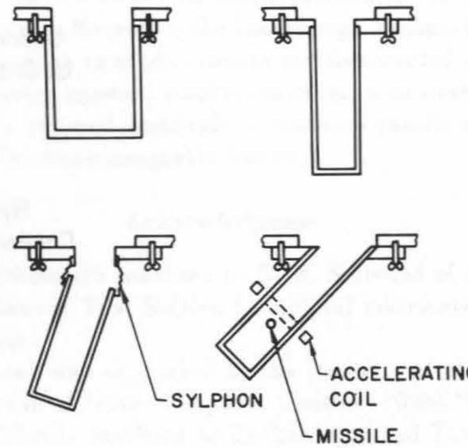

FIG. 3 WELLS FOR LAUNCHING MISSILES WITH ACCELERATING COILS. A COIL FOR OBLIQUE LAUNCHINGS IS SHOWN.

Propulsion System

A unique feature of the tank is its magnetic propulsion system for small missiles. A sphere or spherical shell of large magnetic permeability is located on the axis of a coil of wire whose radius is large compared to the sphere (to minimize hydrodynamic interference) and the coil-winding cross-section. Since the coil-winding cross-section is small, the magnetic field generated by a current in the coil is very nearly a product of the number of turns times the field due to the current in a single turn. The large coil radius makes the electromagnetic coupling between the coil and sphere rather poor, but it does provide for a relatively simple mathematical treatment which assumes that the average magnetic field of the coil is not appreciably affected by the presence of the sphere. If a pulse of current passes through the coil when the sphere is on axis, but not in the center of the coil, the sphere will be drawn toward the coil center with a force proportional to the spatial gradient of the energy in the magnetic field. The field energy is proportional to the square of the current and hence if the current is turned off when the sphere reaches the coil center, the sphere will continue in its path along the coil axis without deceleration from magnetic forces. A means is thus provided for propulsion that does not depend on the presence of a nearby object or disturbance such as an explosion or gas release. Examples of accelerating-coil launchings are shown in Figs. 4 and 5.

The wave tank and coil holder were constructed of non-magnetic and non-conducting material in order that there would be no reaction force on the coil due to their presence. In this case, the force on the coil is equal and opposite to the propelling force applied to the missile. The coil may therefore be instrumented externally and direct measurements of this force may be made without any attachments to or telemetering from the missile. In conjunction with photographically recorded displacement-time records, these data may be used to yield information on virtual mass and drag under conditions of suddenly accelerated motion. The acceleration may be from rest or from motion with an already established wake. The former case should agree with established theory for short times but the latter is a more difficult situation in which data are needed to guide theory.

Forces due to eddy currents in the missile are small compared to magnetization forces when the rate of change of the field from the coil is not too great. An eddy current drive could have been used were it not for the fact that this would make it more difficult to obtain an impulse of appreciable duration. To impart sufficient momentum to the missile, a short-duration impulse would involve large missile (and fluid) accelerations that could introduce unwanted cavitation or other effects undesirable for some tests.

Since the propulsion force on the magnetic sphere is a true body force rather than a contact force, it avoids the possibility of generating elastic waves within the sphere itself that might be objectionable if one were interested in hydroelastic effects and did not want extraneous waves to be generated.

As an indication of performance of the system, a 1-inch-diameter stainless steel sphere attained an underwater velocity of approximately 90 fps in 2 inches of travel from rest for an expenditure of 1500 watt-seconds of electrical energy when a 1½-inch-ID accelerating coil was used. With an 8-inch-ID coil, a velocity of about 50 fps was observed for about 20,000 watt-seconds of energy. The great reduction in efficiency with coil size was to be expected. Although sufficient energy is available for present working needs, another capacitor bank, that will provide a total of 54,000 watt-seconds, is planned. In applications where a small coil is permissible, velocities of the order of 500 fps should be possible. The period of acceleration of the missile may be varied by adjusting parameters in the electrical circuit and the missile may even be made to describe oscillations if desired.

Wave System

The tank wave channel (Fig. 1) is 15 feet long, 1½ feet wide, and 2 feet high. The maximum (undisturbed) water level for wave studies is about 1½ feet. A rigid

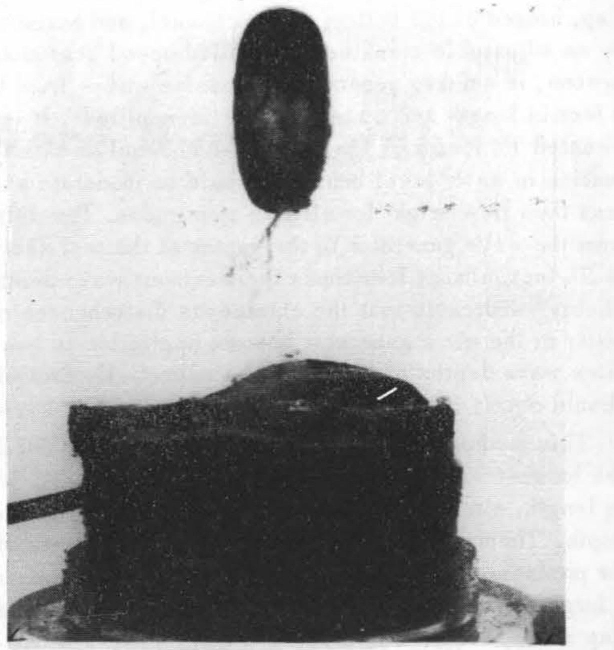

FIG. 4 CAVITATING 1-INCH-DIAMETER STEEL SPHERE LAUNCHED VERTICALLY UPWARD BY SUBMERGED ACCELERATING COIL. SPHERE VELOCITY APPROXIMATELY 65 FPS WITH ATMOSPHERIC PRESSURE OVER THE WATER SURFACE. A RUBBER CUSHION OVER THE COIL PREVENTS POSSIBLE DAMAGE ON MISSILE FALL-BACK. EXPOSURE TIME (FLASH DURATION) APPROXIMATELY ONE MICROSECOND.

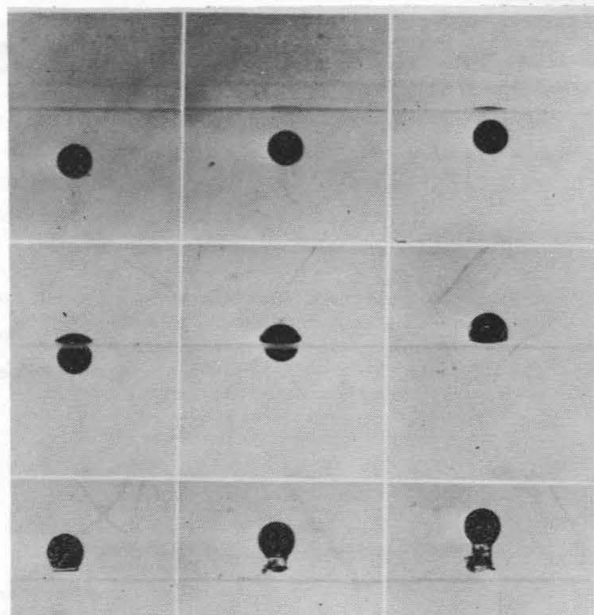

FIG. 5 WATER-EXIT BEHAVIOR OF 1-INCH-DIAMETER STEEL SPHERE LAUNCHED VERTICALLY UPWARD BY SUBMERGED ACCELERATING COIL. SPHERE VELOCITY APPROXIMATELY 50 FPS WITH ATMOSPHERIC PRESSURE OVER THE WATER SURFACE. EXPOSURE TIME (FLASH DURATION) APPROXIMATELY ONE MICROSECOND. TIME BETWEEN SUCCESSIVE EXPOSURES 1/1500 SECOND.

flap, hinged at the bottom of the channel, and actuated by an adjustable crank and controlled-speed gear-motor system, is used to generate progressive waves from 1 to 3 feet in length and up to 3 inches in amplitude. It is situated 1½ feet from the end of the channel so that fluctuation in water level behind it would be moderate and less than flap height for all flap amplitudes. The distance from the wave generator to the center of the test section is 5½ feet, almost four times the maximum wave depth. Theory[1] indicates that the extraneous disturbances of the water at the wave generator become negligible in two or three wave depths of travel; hence essentially free waves should obtain in the test section.

This method of generating waves was chosen because the longest wave contemplated for study is about 3 feet in length, a relatively short length compared to the water depth. Theory[1] indicates that this generator is suitable for producing such waves. Moreover, it does not possess a large inertia characteristic, is easily regulated, and the flap motion required to produce a desired wave is calculable.

No wave absorber is presently planned because the wave channel, extending 8 feet beyond the center of the test section, is sufficiently long that four of the longest waves (3 feet) can pass the center of the test section before the reflected waves return. It is believed that the wave train will stabilize and tests can be completed within this period. Tests of longer duration may require a wave absorber.

Conclusion

The unique construction of the Variable-Atmosphere Wave Tank and associated launching equipment may provide a means to estimate hydrodynamic forces on the accelerated missile from reactive forces on the launching coil, and hence a means to obtain information on virtual mass and drag. Moreover, the launching equipment may provide a means to study missile and associated cavity behavior under unusual conditions, e.g., a cavitating missile that is stopped suddenly or made to oscillate back and forth by electromagnetic forces.

Acknowledgment

The authors are indebted to G. W. Stubstad of the U.S. Naval Ordnance Test Station for helpful comments and suggestions.

This work was supported by the Department of the Navy, Bureau of Naval Weapons, Contract N600(19)59368 to the California Institute of Technology, and Task Assignment No. RRRE-04001/216-1/R009-01-01 to the U.S. Naval Ordnance Test Station.

[1] J. Ross and C. E. Bowers. "Laboratory Surface Wave Equipment," St. Anthony Falls Hydraulic Lab., University of Minnesota, Minneapolis, Minn., Project Report No. 38, November 1953.

This article appeared in *Cavitation Research Facilities and Techniques*, 1964, The American Society of Mechanical Engineers, United Engineering Center, 345 East 47 Street, New York, N.Y. 10017.